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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

METAL WORKING LUBRICANTS

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LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

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METAL WORKING LUBRICANTS

THE industrial position of the United States of America is the foremost in the world today. One of the most significant material factors associated with industrial development is the metal industry which includes the production of metals, and the working, or forming of them into useful tools and objects. These tools and objects enable and accelerate development in other industries, in addition to those which furnish end-use metal goods. The economy of the United States is closely associated with iron and steel production. As our economy flourishes, steel production increases; on the other hand economic lulls are accompanied by corresponding reductions in steel output. Steel output is therefore an excellent index to our prosperity because it indicates the level of activity in the varied industries that contribute to this prosperity.

In 1958 the iron and steel industry of the United States maintained its world leadership in steel-making *capacity* which was 147,633,670 net tons[1] and which exceeds that of the second largest steel-making nation by about 80 million tons.

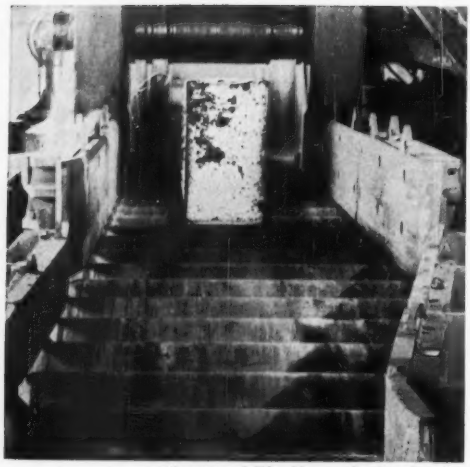
Iron and its alloy called steel[2] have but little intrinsic value, and are valuable only to the extent that they can be worked and thereby upgraded into the shapes and forms that are the backbone and the profile of our industrial nation.

From the time the glowing ingots of steel are taken from the "soaking" furnaces and reforming of the metal is begun in a spectacular shower of sparks to the time they are fabricated, through metal working processes, into the heavy structural members of buildings and bridges, or into amazing complexities of forms in machine tools, engines, and electronic computers, or into the stringently sized components of ballistic missiles, – men and their machines are constantly striving to produce steel products of better quality at faster rates and lower costs. Similar efforts are being made with other metals such as aluminum, copper, and such rarer ones as titanium, zirconium, tantalum, all of which are becoming increasingly important.

One of the ways in which the petroleum industry has had a part in these ever expanding activities is in supplying lubricants for the many metal working processes. The metal working lubricants play a vital role in increasing the efficiency and productivity of metal working machines. It is the purpose of this article to describe, in general terms, metal working lubricants and the role they play in rolling, forging, drawing, cutting and grinding metals.

Metal working lubricants have contained an almost innumerable variety of constituents such as mineral oils, asphalts, fatty oils and fatty acids, soaps and other emulsifiers, synthetic detergents and oils, inert and active solid fillers, chemical additives of several types and purposes, waxes, resins and water. The oils and fats as well as some of the other materials are often sulphurized, chlorinated or phosphorized to provide specific performance characteristics.

1. Steel Facts No. 153, February, 1959.
2. Magazine Lubrication, Oct. 1958, "Steel Mill Lubrication".



Courtesy of The Morgan Engineering Co.

Figure 1 — White-hot ingot on back table of blooming-slabbing rolling mill. Note water sprays which cool upper roll and loosen scale on ingot.

HOT ROLLING OF STEEL

Excepting the negligible quantity of steel castings that are made from molten steel poured directly into molds from the furnace, all other steel products originate in a cast steel ingot weighing from four to fifteen tons. Hot rolling is the most common initial process of a long series which will eventually upgrade the ingot into blooms, billets, slabs, plates, railroad rails, structural steel girders, bars, rods, sheets, tin-plate, pipe, tubing, wire and the multitude of other steel products. Some of these are used as received; others merely furnish the raw material for further processing into finished products. The smelting of iron ore into pig (cast) iron, its conversion into steel, and many of the early upgrading processes are described in a previous issue of this publication[2].

Hot rolling takes advantage of the greatly increased plasticity of steel at high temperatures and greatly reduces the tremendous pressures that are necessary to form the metal. It not only facilitates reforming the metal into simple rods and bars, but is the only practical method of obtaining such compound shapes as railroad rails and structural steel. As illustrated in Figure 1, hot rolling begins when the white hot ingot at a temperature of about 2100°F. is passed repeatedly through the rolls of a blooming-slabbing mill. Because the metal is hot and soft, large reductions in work dimension can be made during each pass through the rolls. No lubricant is needed between the mill rolls and white hot metal and few would survive. However, large quantities of water or water solution are sprayed against the rolls to cool them, and onto the ingot itself to help remove the flaky iron oxide mill scale which forms rapidly at high temperatures.

In addition to its shaping ability, hot rolling considerably refines and improves the strength and other metallurgical characteristics of the metal. Principally because of high working temperature and oxide formation, hot rolling is not capable of producing either good surface finish nor good dimensional accuracy nor the highest metallurgical characteristics, consequently, these must be enhanced by additional metal working processes.

COLD ROLLING OF STEEL

Cold rolling of steel increases its density, strength, hardness, surface finish and permits more precise sizing and better suitability for subsequent metal working processes, or direct fabrication. While the process is used for some plate, bar and rod production the major item is steel strip, either bright or black, or tin-plated. The mill rolls are finely finished to permit corresponding finish on the strip, and rolling is performed with the assistance of a film of "roll oil" between rolls and strip. The primary functions of a roll oil are to adhere to, lubricate, cool, and protect both strip and rolls against rust, abrasion and other damage, but the special requirements of subsequent processing can add many others.

Since the cold steel is highly resistant to deformation, the reduction in strip thickness accomplished by a pair of rolls is relatively modest, consequently several rolls or "stands" are used in tandem as illustrated in Figure 2. Some high speed tandem mills are capable of operating at speeds as high as 7000 surface feet per minute (SFPM) at the last stand; however, such a speed is seldom attained in actual production and 3000 to 4500 SFPM is more normal.

Since the metal "work hardens" as it is rolled, one or more intermediate annealing operations may be required to soften and keep it amenable to further working. Annealing often presents a most stringent requirement for the roll oil, since in addition to its other characteristics it must burn off cleanly and avoid staining or otherwise harming the finished strip. A roll oil should be easy to apply but also easily removed if subsequent operations include plating, tinning or painting.

Roll action appears to be a combination of rolling (which draws the metal through the rolls and reduces its thickness) and slipping (which burnishes and improves surface finish). Thus a roll oil must provide a proper frictional balance between role "bite" and strip slippage. If too little lubrication is provided the strip surface may be torn and metal "picked up" by the rolls. This not only causes rejection of the strip but the metal picked up on the rolls

2. Magazine Lubrication, Oct. 1958, "Steel Mill Lubrication".

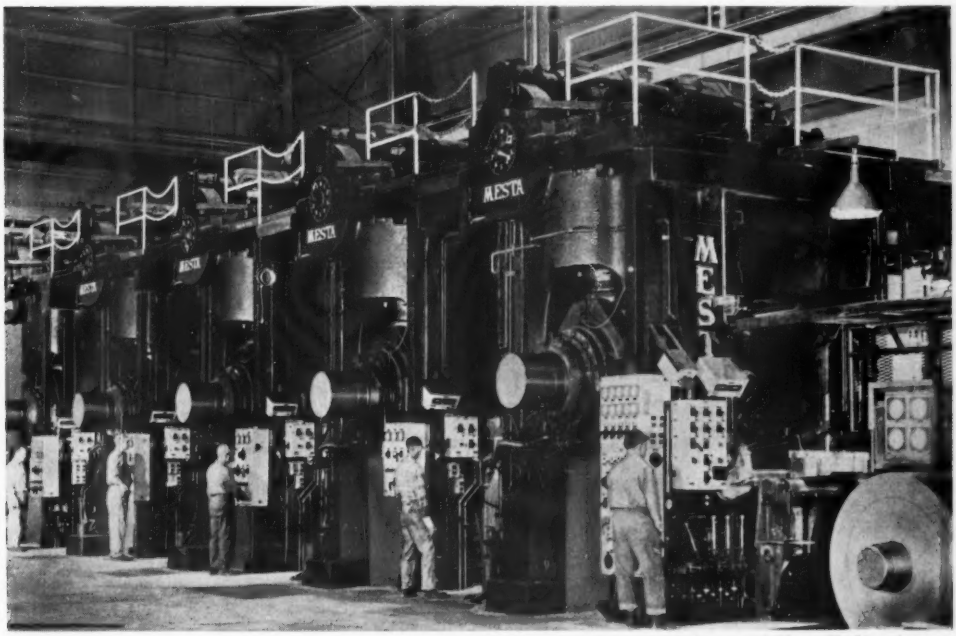
may cause surface damage during subsequent rolling. If too much lubrication is allowed, the rolls will slip and improper reduction results; this excessive slippage of the rolls is called "lack of bite". Surface finish also depends upon many variables such as the steel itself, the amount of reduction per pass, type of roll, type of roll oil, method of application and cleanness of roll oil, and preliminary annealing or pickling operations.

Palm oil, palm oil substitutes and mineral oils are sometimes sprayed on the rolls and workpiece "neat" but generally the rolls are simultaneously flooded with large quantities of water for cooling purposes. In some systems, the roll oils and water are physically admixed before application. Stable emulsions are usually employed in circulating systems, whereas, the unstable types are applied sparingly in "once-through" operations with no attempt at recovering and reusing them. Sometimes efforts are made to recover the oily phase of the used roll oil.

Historically, palm oil though costly and sometimes difficult to obtain is still considered nonpareil for rolling tinplate, but less expensive palm oil substitutes have been developed which are satisfactory for black plate and other less demanding applications. Many types of materials have been evaluated "neat" and in various combinations with each other or mineral oils as palm oil substitutes. These include various vegetable and animal fats and fatty acids, esters, glycerides, soaps, high molecular weight alcohols, petrochemicals, various synthetics, etc. Many specific formulations have been found to perform satisfactorily, and the use of palm oil substitutes is being extended. Table I summarizes the types and specific applications of roll oils used in cold rolling steel with conventional rolling mills.

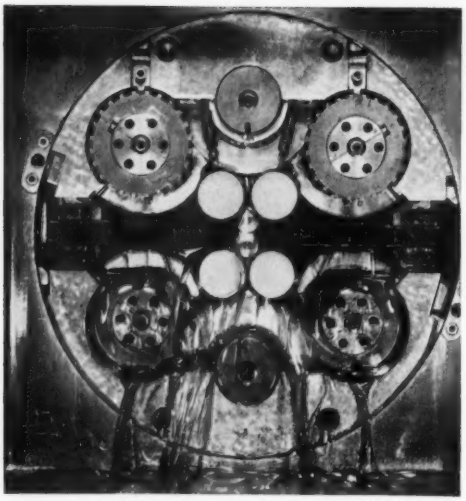
Cold Rolling in Sendzimir Mills

The unique Sendzimir mill is designed to cold roll metal strip to close dimensional tolerances and to very thin gauges with fine surface finishes. As illustrated in Figure 3, this mill uses relatively small work rolls (usually less than 2⅛ inches in diameter but as much as fifty inches in width) backed up by a cluster of rolls to provide rigid support and permit very accurate sizing. Small diameter work rolls produce a high degree of metal working which is very desirable for improving metallurgical properties of the rolled strip. It is claimed this mill can roll even alloy steel strips to 0.001 inch thickness without annealing. Some of the metals which are reduced in Sendzimir mills include carbon, silicon, and stainless steels; aluminum; brass; molybdenum;



Courtesy of Mesta Machine Company

Figure 2 — A 48 inch four-high five-stand tandem rolling mill used for cold-finishing steel strip. Note finished strip emerging from the final stand and being coiled at reader's right.



Courtesy of The Waterbury-Farrel Foundry & Machine Co.

Figure 3 — Cross view of a Sendzimir reversing mill showing the ⅞ inch work rolls and flooded lubrication.

titanium; tantalum; copper; beryllium copper; phosphor bronze; gold and gold plate; stellite; silver; nickel silver; tin and numerous alloys.

Requirements of Sendzimir Roll Oils

Sendzimir mills have special requirements for roll oils which differ from those of the regular strip mills in that the oils serve not only as coolants and lubricants for the rolls and strip but also as lubricants for the roll bearings. Furthermore the oil is recovered, filtered and recirculated. Thus a Sendzimir roll oil may be required to lubricate the roll bearings, control "bite" and slip, cool rolls and strip, be non-staining before and after annealing, prevent rust on bearings and rolls, and be resistant to foam, oxidation and fogging.

Use of Mineral Oils

For Sendzimir mills producing relatively thick strip, mineral oils generally in the viscosity range of 100-150 SUS at 100°F. are used. For rolling of thinner gauges of metal and foil, lower viscosity oils (45-65 SUS at 100°F.) are more suitable. The mineral oils may be used straight, or may be compounded with various fats, EP additives and oxidation inhibitors to give improved performance depending upon the specific operations involved. Low viscosity mineral oils are used to take advantage of their greater cooling effects than high viscosity products. Due to the better cooling provided, higher production rates can be obtained.

Due to the nature of the Sendzimir operation, including the fact that its roll oil is recirculated, oil must be kept clean and is almost always filtered. Filter life is an important economic consideration and this is related to some extent to the stability and oxidation resistance of the roll oil used. In some instances, the roll oil is used without changing but with make-up oil being added as needed. Other mills may discard and replace the oil periodically.

Use of Emulsions

Rich soluble oil emulsions (about 20% soluble oil and 80% water) are sometimes used in Sendzimir mill operations involving rolling of low and medium carbon steels. These emulsions possess the advantages of greater cooling, increased throughput, less staining, and less fogging during operations. They have the disadvantages of allowing

TABLE NO. I
Cold Rolling Oils

	Some Uses
1. Palm Oil	Tin plate, black plate
2. Palm Oil Substitutes Usually various compositions of fatty oils and acids. No mineral oils included.	Tin plate, black plate
3. Mineral Oils Generally in a Saybolt Universal viscosity range of 100 to 150 seconds at 100°F.	Plate and heavy gauge strip
4. Stable Emulsions May contain mineral oils, palm oil, palm oil substitutes and various quantities of some emulsifiers or special soluble oils.	Automotive body panel stock
5. Unstable Emulsions May contain various quantities of mineral oils, waxes, fatty oils and fatty acids as well as small quantities of emulsifiers.	Black plate

higher wear of the roll bearings and they become dirty and hard to clean. Emulsions often have to be discarded within 30 days of operation.

ROLLING OF ALUMINUM

The equipment used for the rolling of aluminum is similar in design and size to that used for rolling steel. Due to the greater ductility of aluminum however it is possible to make a greater reduction per pass in rolling operations. The ingots used as starting material may be cast or extruded. Rolling speeds may vary from 200 SFPM in single stand mills to 1800 SFPM in tandem mills. High speed mills, particularly for foil rolling, are capable of speeds exceeding 3,000 SFPM. Foil production in 1957 was estimated at 119 million pounds and it was projected that its production would reach 300 million pounds by 1960.

Hot Rolling of Aluminum

Hot rolling of aluminum is done at much lower temperatures (575°F and above) than those used in the hot rolling of steel. Generally, the two opposing large faces of the heated ingot are cleaned prior to rolling by machining in a "scalping" operation. Some hot rolling is done, however, in the "as cast" state. Like the hot rolling of steel, this is usually a preliminary operation to the finish cold rolling.

Soluble Oil Emulsions

Water alone cannot be used as coolant in the hot rolling of aluminum because of adverse staining of the strip and because water's lack of "lubricity" allows excessive metal "pick up" on the work rolls. On the other hand, mineral oils, even of low viscosity, do not have sufficient cooling capacities, or sufficiently high flash points to be satisfactorily or safely used alone. As a result, soluble oil emulsions are used almost exclusively as metal working lubricants in hot rolling. The aqueous phase of the emulsion provides the cooling capacity, and the oily phase, the lubricity desired. It should not be assumed however that any emulsion will be satisfactory. In fact a large amount of work has been done to define the characteristics of satisfactory emulsions on the basis of simulated service and bench type tests.

Requirements of Hot Rolling Fluids

Some of the desirable properties of soluble oils used in hot rolling of aluminum are: reasonable emulsion stability, good wetting properties, non-staining characteristics and long emulsion life.

Soluble oils which have been found suitable basis actual service tests contain in the range of 15% emulsifiers plus additional quantities of fatty oils or fatty acids, mineral oils and various combinations of coupling agents and solvents. Soluble oils containing mineral oils with viscosities approximating 200 SUS at 100°F. have been satisfactory and in some operations much higher viscosity mineral oils have been used. Concentrations of the emulsions used vary in the range of 1% to 10% depending upon the specific operation, the alloy being rolled, the degree of lubricity desired, surface finish requirements, etc.

The relationship between lubricity and roll "bite" described for steel rolling is generally more critical in aluminum rolling, as the softer metal tends to be "picked up" more easily on the hard work rolls. Some factors affecting roll "pick up" are: degree of lubrication, type of alloy, reduction per pass, rolling temperature, cleanness of emulsion, scalping, and roll finish.

The emulsions used for rolling are generally contained in large central systems and are sprayed or flooded on the aluminum in the quantities necessary for proper rolling. Since the emulsion is recirculated, it is essential that it be properly cleaned. This may be done by first settling in large pits or tanks followed by use of centrifuges or various filtering devices.

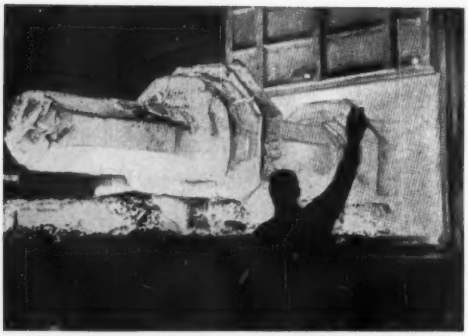
COLD ROLLING OF ALUMINUM

Soluble oil emulsions are not generally satisfactory in cold rolling aluminum due to staining of the strip, and lack of lubricity. Therefore, mineral oils, as such, or containing various percentages of fatty oils and other additives are almost universally used. Low viscosity mineral oils, which have better cooling effects and anti-staining characteristics than high viscosity oils, are generally used. Mineral oils in the viscosity range of 40 to 60 SUS at 100°F. have been found suitable and some mills use lower viscosity oils (30 to 40 SUS at 100°F.) for foil rolling.

The lubricating characteristics of low viscosity mineral oils are usually adequate, however, temperatures may rise to about 300°F. in cold rolling due to frictional factors so it is desirable to have the flash points of the oils as high as possible to minimize the danger of fires.

Possible staining of the aluminum during an annealing operation is one of the most critical requirements of the roll oil. Annealing temperature may vary from about 600 to 800°F. depending upon the alloy and the annealing effect desired. In selecting a mineral oil for cold rolling, consideration is given to the composition of the oil and to its distillation characteristics, to insure ease of removal in the annealing operation and thereby minimize staining. It is also desirable that the oil possesses good resistance to oxidation and oxidation inhibitors are often included when necessary. Organic esters and other additives may be used for specific purposes.

Mineral oils used in cold rolling are applied by spraying the rolls and workpiece, and are maintained in central circulating systems. It is essential



Courtesy of United States Steel Corp.

Figure 4 — Large steel forging emerging white-hot from heat treating furnace and ready for further forging.

that contaminants such as aluminum oxide and dirt that enter the oil be removed before the oil is returned to the working area. For this reason, the oils are usually centrifuged or filtered.

HOT ROLLING COPPER AND BRASS

The hot rolling of copper and brass is generally done without the benefit of roll oils or coolants. In some instances, fatty oils have been used, but there appears to be little gained by their use in the rolling process and these products have the drawbacks of causing difficulties due to oxidation and odor formation.

COLD ROLLING COPPER AND BRASS

Roll oils in most wide-spread use are generally petroleum oils containing from one to four percent of fatty oils or combinations of fatty oils and fatty acids, depending upon the specific operation requirements. Types of roll oils in use and their general characteristics are shown in Table II.

It has been found that the use of chlorine and sulfur bearing additives are objectionable. Chlorinated materials often cause pinkish discolorations of the strip. Sulfur bearing additives and high sulfur mineral oils generally cause black discolorations, particularly in the annealing operations.

The lubricant is generally dripped onto the strip ahead of the rolls, and is subsequently spread over the strip with "eveners." Water is used for cooling the rolls and the roll lubricants are recovered from the water in central sumps.

FORGING

Forging increases the density, toughness and strength of metals by grain deformation just as does rolling. Cold forging is more effective in upgrading metallurgical properties than hot forging. Some important forging operations are: Smith Forging, Drop Forging, Machine or Upset Forging, Press Forging, Roll Forging and Coining. Discussions of some of the equipment used in forging are given in an earlier issue of this publication[3].

In general, forged parts are produced in piece lots and the primary factors affecting costs are the rapidity of production and die life. Dies are made of hard steels or more usually tungsten carbide, which due to its extreme hardness, has been found to be especially well suited for these operations. These dies are very expensive and every effort is made to extend die life.

The quality of forged articles depends upon a number of factors, including materials of construction, degree of working of the metal, surface finish and the trueness of form to the carefully prepared die. These last two factors are not critical in the case of some large rough forgings like that shown in Figure 4 which are ultimately machined extensively, but are extremely important in instances where finished form or almost finished form, is expected. The selection and proper use of the correct lubricant can

3. Magazine Lubrication, Sept. 1947, "Lubrication in Forging Operations".

TABLE NO. II

Roll Oils for Cold Rolling Copper and Brass

Oil Type	*Characteristics*
1. Compounded mineral oils with viscosities of 65-85 SUS at 100°F.	Good finishing oils, and provide good polish to the strip.
2. Compounded oils with viscosities of 100-150 SUS at 100°F.	The bulk of the oils used fall in this category.
3. Compounded mineral oils of approximately 250 viscosity SUS at 100°F.	Heavy duty oils used when high roll pressures are involved as in the rolling of phosphor bronze.
4. Soluble Oil emulsions in concentrations 10:1 to 30:1.	Used where specific surface characteristics are desired.

have an important effect upon surface finish and trueness of form as well as upon die life. The use of the wrong lubricant, or too little lubricant may cause metal "pick up" and wear. Too much lubrication or ill placed lubricant can cause improper metal slip and result in unfilled die sections or otherwise improperly formed forgings.

Factors Affecting Die Life

Some of the primary factors affecting die life are die material, material being worked, die finish, lubrication of die and work, cooling of die, operating temperature, and the abrasive action of scale.

The primary requirements of the lubricants used in forging are to cool the dies, and to lubricate so as to minimize frictional effects at the surface of the workpiece as it slides over the die. This enhances metal flow and minimizes metal "pick up" and die wear.

Hot Forging

In hot forging the temperature of the workpiece is usually quite high and die temperatures may range from 300°F. to 600°F. Due to the high temperatures involved, conventional mineral oil type lubricants burn off rapidly and are usually ineffective. Therefore hot forging lubricants almost invariably contain some solid "filler" materials such as graphite, talc, mica, and molybdenum disulfide, which resist combustion and provide solid film lubrication. In some instances black oils and heavy residual oils can be used satisfactorily, primarily due to their high carbon forming tendencies on combustion. In hot forging of some soft metals, such as aluminum, if graphite is used it may become embedded in the workpiece and rigorous cleaning procedures may be entailed.

Filler contents in hot forging compounds vary in the wide range of 4 to 50 per cent. The products of higher filler content are used in the more severe operations. The type and form of the fillers as well as particle sizes are important considerations.

A wide variety of vehicles are used with the fillers such as water, naphtha, low viscosity mineral oils, volatile solvents, etc. Advantage may also be taken of the viscous effects and high carbon residue forming tendencies of asphaltic products, residual mineral oils such as black oils, heavy fuel oils, cylinder stocks, etc.

Soaps are generally used in these formulations to aid dispersion and deter settling of the fillers. These soaps also contribute to lubrication in the process. For the preparation of water soluble compounds alkali metal soaps are best whereas for oil soluble formulations alkaline-earth or other heavy metals soaps are used. The fatty component of the soaps may be tallow, tallow acids, rosin acids, degras, etc.

Hot forging compounds are made in consistencies varying from very fluid liquids to heavy pastes. In usage the various forging lubricants may be applied "as is," or diluted with water or mineral oil, depending upon the requirements of the operation.

Cold Forging

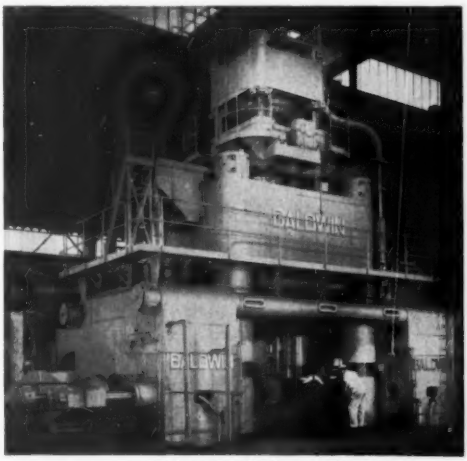
In cold forging, the requirements of the lubricant are somewhat different than in hot forging in that there is less requirement for cooling of the dies but more need for proper lubricity to enhance metal flow and deter metal "pick up." Figure 5 illustrates a large cold forging operation and the reader may correctly infer that high work pressures are frequently required.

Since temperatures are relatively low in cold forging it is often possible to use conventional lubricants such as mineral oils, mineral oil-fatty oil blends, etc., without the need of fillers. This is particularly true for soft metal forging and in moderate steel forging operations. For the more severe operations solid filled products such as described for hot forging are used. In addition, fatty oils and EP additives may be included to improve specific performance requirements. Emulsifiable formulations may be used as such, or cut back with water. The emulsifiable products are readily removed from the forged parts by aqueous washes.

In some operations, such as cold heading of bolts, the workpiece may be coated with a lime slurry and dried. The coated material may then be forged using a mineral oil, or emulsifiable lubricant.

Application of Lubricants

In forging, two methods of lubricant application



Courtesy of Cameron Iron Works, Inc.

Figure 5 — An 11,000 ton multiple ram forging press being used to cold-forge steel.

Courtesy of Automobile Manufacturers Association

Figure 6 — Press drawing flat steel sheet into automobile door. Note brush application of lubricant to certain areas of sheet where heaviest drawing occurs. Also see large automobile top panel in background from another press.

(1) swabbing and (2) spraying, are in general use. The more fluid products are usually sprayed and the heavier products applied with swabs.

The proper selection and application of forging lubricants is an important part of their use. Judicious use of lubricants can minimize excessive flaming, prevent build up of undesirable ash residues and scale deposits, and assist in removing the forged part from the die.

Recent Trends

Recent progress in forging has been toward minimizing the necessity of additional machining steps on forged parts and in overcoming high production costs of low production items. A step in the latter direction has been taken in the development of relatively low cost die inserts to reduce high die costs.

DRAWING

There are various metal forming processes referred to generally as "drawing" which include press drawing, tube and bar drawing, and rod and wire drawing.

Press Drawing

Press drawing encompasses such operations as shallow drawing, deep drawing, cupping, ironing, forming, blanking, and stamping, which are generally performed on sheet, strip or flat metal pieces rather than billets, rods, etc.

The growth of press drawing has followed to a large extent the growth of the automotive industry. Drawing operations such as illustrated in Figure 6 are used extensively to shape body roofs and panels, bumpers, housings, metal covers, etc., as well as

pots and pans, seamless containers, and many other articles in the appliance fields.

Annealed tool steels, cast iron, hardened steels, and carbides have proven suitable as die materials. The costs of these dies are generally high and it is important to choose the proper lubricant to extend their life and reduce unit costs. Good surface finish of drawn parts is often extremely important and in many operations tears, scratches, wrinkles, etc., cannot be tolerated. The selection and proper application of the right lubricant can minimize costly rejects and boost production rates.

Functions of Drawing Lubricants

The primary functions of a good drawing lubricant are to provide a suitable lubricating film between the dies and workpiece which allows the desired metal flow, to coat the dies and workpiece, to prevent scoring or wrinkling of the work, and to minimize metal "pick up" on the dies.

In drawing, as in some forging operations previously discussed, it is necessary to provide balanced lubricity to obtain the proper degree of metal deformation and the flow of the metal over the die surface to produce the desired results.

Aside from their primary functional requirements, there are a number of other characteristics *some of which* may be required in drawing lubricants as follows:

1. Be easy to apply. Dip, spray, roll or swabbing method of application may be involved.
2. Should not interfere in subsequent operations. It may be desirable to coat or weld the finished part without prior washing.
3. Adhere to the die and workpiece properly.
4. Be easy to remove if desired.
5. Prevent rusting of workpiece or die.
6. Mix readily with water and provide a satisfactorily stable mix.
7. Provide a lubricating film for subsequent operations.
8. Possess satisfactory physiological properties and possess or develop no offensive odors on use.
9. Possess satisfactory stability.

Some general types of drawing lubricants are as follows:

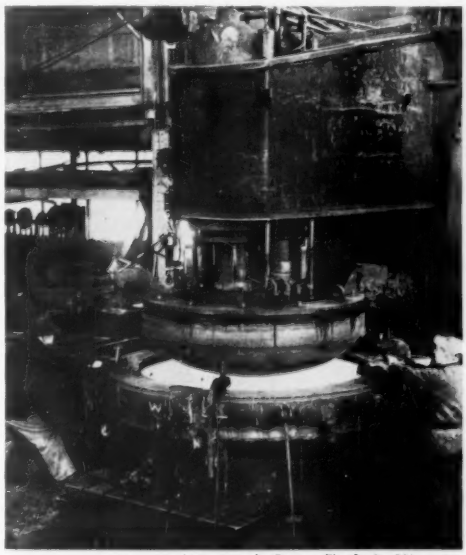
1. Non-emulsifiable
   - Mineral oils
   - Mineral oil-fatty oil blends
   - Sulfurized and chlorinated oils
   - EP oils containing lead soaps
2. Emulsifiable non-pigmented
   - Soluble oils
   - Soap thickened compounds
3. Emulsifiable pigmented.
4. Dry films

Straight mineral oils of various viscosities ranging from about 100 SUS at 100°F. to heavy bodied residual oils may be used for aluminum, copper and steel drawing. The choice of viscosity is dependent upon the severity of operations with the heavier oils being used where greater film strength is required. When additional lubricity is needed for heavier drawing, fats, fatty acids and other oiliness agents are included. Oils containing sulfur, chlorine or other E.P. additives such as lead soaps, may be required in severe operations involving steel, and have been effective in drawing stainless steel. Oils containing active sulfur and chlorine are not generally used in drawing copper because of adverse chemical effects and staining.

Emulsifiable Non-Pigmented Lubricants

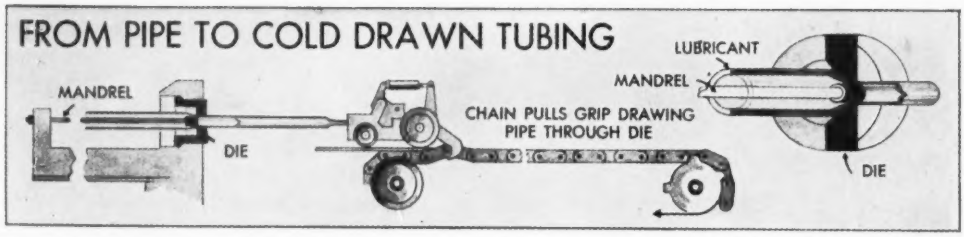
Conventional soluble oils can be used in light drawing, forming, blanking, stamping, etc., of aluminum, copper and steel. Heavy duty soluble oils can be used to advantage in some operations. These soluble oils may be used "neat" or as aqueous emulsions.

A special class of these lubricants are the soap thickened products that may vary from semi-fluid compositions to thick soap-fat pastes. The more fluid formulations usually contain special soaps,



Courtesy of Graver Tank & Mfg. Co.

Figure 7 — A 400 ton forming press used to shape white-hot steel plate. Aqueous mixes (1:1) of highly pigmented drawing compounds are used in such operations. When aluminum is worked in this manner lower temperatures are involved and pigmented compounds are used in undiluted form.



Courtesy of Iron & Steel Institute

Figure 8 — A simplified schematic sketch illustrating plug drawing of pipe to tubing. Lubricant can be applied externally to the pipe at a point just prior to its entering the die and also to the internal work area by means of a drilled mandrel.

mineral oils, solvents and water. These products are easier to apply and to emulsify, if desired, than the thick pastes. Such products have been satisfactory in mild operations with steel and in deep drawing of aluminum. These lubricants may be used as is, or in aqueous mixes with water in concentrations as low as 10 per cent, depending upon the operation.

The choice of emulsifiable over the non-emulsifiable formulations in many operations is dictated by their greater cooling efficiency, ease of removal from the workpiece, and lower costs.

Emulsifiable Pigmented Lubricants

Emulsifiable pigmented lubricants can be satisfactorily employed in many drawing applications on steel, aluminum and copper in both hot or cold operations. These lubricants are usually thick compositions comprised of alkali metal soaps, mineral oils, additives, water and solid fillers. Fillers used are generally talc, mica, graphite, etc., similar to those used in hot forging lubricants previously described. Filler contents may vary from 5 to 50 per cent.

These lubricants are used "as is," and in many applications, including the hot deep drawing of steel shown in Figure 7, they may be used as aqueous mixes. Concentrations of the aqueous mixes may range as low as 10 per cent depending on the application. For some severe operations such as deep drawing of stainless steel, the highly pigmented products may be further fortified with sulfurized oils or other E.P. additives.

Dry film lubricants are often applied to sheet and strip prior to drawing. Some of these materials are various soaps, waxes or waxy compounds which are usually applied to the metal hot, or in hot aqueous solutions and allowed to dry before use. Other lubricants are applied before drawing, if needed. Phosphate coatings are gaining usage. Usually a lubricant is needed in working phosphate coated metal, but the phosphate film enhances the performance of the lubricant. For drawing stainless steel, preapplied films of lithopone, linseed oil and shellac have been found effective.

Lubricant Application

The various drawing lubricants can be applied by dipping, spraying, roll coating or swabbing, depending upon the nature and consistency of the lubricant. When the emulsifiable pigmented products are reduced by dilution, agitation should be used to keep the fillers in suspension.

Tube and Bar Drawing

Tube and bar drawing entails reducing the diameter of the workpiece by pulling it through a fixed die. The tubes or bars are first "pointed" by swaging so the point can be inserted through the die. The swaged end is gripped by jaws in a block and the remainder of the workpiece is pulled through by means of the draw bench equipment diagrammed in Figure 8.

Tubes are drawn by several methods including the following:

1. Die Sinking

The tube is drawn through the dies without the use of an inner tool or plug. Wall thickness cannot be controlled by this method.

2. Plug Drawing

In this method a plug, positioned in the die, is held inside the tube by a mandrel, as the tube is drawn. This is a severe operation and the tube is reduced in both wall thickness and diameter. This method allows control of the inside diameter.

3. Rod Drawing

In this method a long cylindrical rod is inserted in the tube to be drawn and is pulled through the die with the tube. Both wall thickness and outside diameter are controlled in this manner. Rod drawing is usually employed in drawing thin walled tubing where plug drawing is not feasible.

Various lubricants including dry soaps, soap solutions, pigmented drawing compounds, soluble oils, mineral oils, mineral oil-fatty oil blends, E.P. oils, etc., similar to those described under Press Drawing are used in these operations. The pigmented

products and E.P. oils are used on the more severe draws. In many steel drawing applications, the tubes and bars are coated with a lime slurry and dried before drawing. These coated pieces may be drawn, as such, or with the use of other lubricants.

Copper and brass tubes and bars are not usually lime-coated but often heavy greases and pigmented products are used on severe draws. Lighter operations are lubricated with mineral oils and mineral oil-fatty acid blends.

Aluminum is drawn using mineral oils including heavy residual oils. Fats and other oiliness agents are added as needed to supply additional lubricity.

Stainless steel drawing is a very severe operation. Soft metal coatings, lithopone-shellac, lithopone-linseed oil-shellac mixes and highly chlorinated compounds are used in drawing stainless steels.

ROD AND WIRE DRAWING

Rod and wire drawing is similar in operations to tube and bar drawing, however, a series of dies may be used to effect successive reductions for continuous drawing.

The lubricants previously described in tube and bar drawing are also used in rod and wire drawing. There are 3 important groups of lubricants in general usage.

1. Dry Soap Compounds

Various types of dry soaps are used in mild drawing operations. These materials may be pre-applied to the rods or applied in a lubricant box at the entrance to the die.

2. Wet Wire Solutions

Emulsions used contain various emulsifiers and may also contain various percentages of mineral oils, fat and fatty acids as well as E.P. additives as required by the operation. Heavy duty soluble oil emulsions are sometimes used.

3. Drawing Oils and Greases

Heavy greases and pigmented drawing compounds may be used on copper and brass for heavy drawing. A wide variety of oils with or without additional oiliness agents are used. The lubricants are usually applied by circulation to the die or through the use of a lubricant box located ahead of the die.

METAL CUTTING AND GRINDING

Metal cutting and grinding differ from the metal working processes discussed earlier in that the shape of the final object is obtained by progressive removal of metal from the workpiece in the form of chips rather than by plastic reforming of the metal. Such operations include the use of single and multiple point tools as well as abrasive wheels. Volume-wise, usage of metal cutting fluids is quite large and approximately one-half of the total quantity of metal working lubricants used in the entire metal working industries may be consumed in metal cutting and grinding.

The fundamental processes involved in metal cutting and primary requirements of cutting fluids have been dealt with in a previous issue of this publication.[4] In this issue only the general types of cutting fluids and recent trends in these fields will be discussed.

The ability of a fluid to perform the primary functions required of a cutting oil is dependent upon the specific formulation of the product and the conditions and requirements of the specific operation. Often various secondary effects related to the machining operation or to the lubricant are of utmost importance. Due to the great complexity of machining and grinding operations, varieties of metals used, specific requirements, etc., it is necessary to have a sound knowledge of the abilities and characteristics of the various types of cutting fluids to enable selection and proper use of the optimum fluid. Fortunately, sound advice and guidance can usually be obtained from the major lubricant suppliers through trained metal working lubrication engineers. These specialists have a broad view of the over-all aspects of machining, and specific product knowledge, to aid in selection of the proper lubricant. Often the selection of the optimum fluid will increase production, reduce rejections, and may enable elimination of machining steps, all of which lower unit costs.

Cutting fluids used in machining and grinding can be classified broadly as mineral cutting oils and soluble oils.

The general types of mineral cutting oils are:

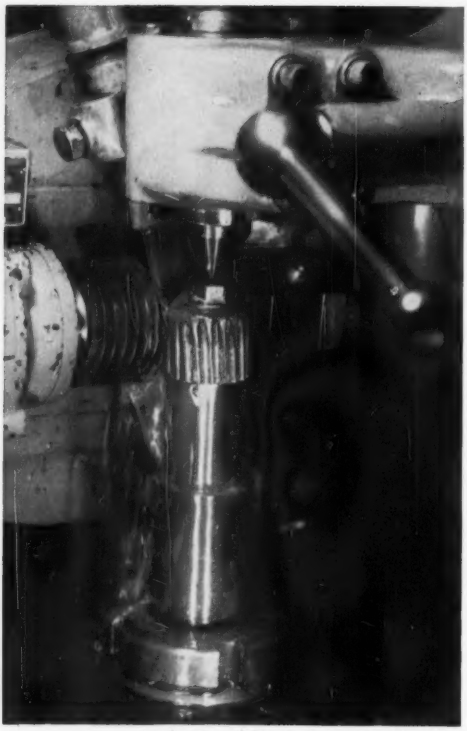
1. Straight Mineral Oils
2. Mineral-Fatty Oil Blends
3. Mild EP Oils
4. Multi-Purpose Oils
5. Transparent Heavy Duty Oils
6. Dark Heavy Duty Oils

Mineral Cutting Oils

Straight mineral oils can be used in some mild metal cutting operations where performance and surface finish requirements are low. When additional oiliness or lubricity is needed, fatty oils or fatty acids may be added to enhance performance.

Paraffinic or intermediate base mineral oils are generally preferred for such products because they generate less fog or smoke than a naphthene oil.

4. Magazine Lubrication, April 1956, "Cutting Fluids".



Courtesy of D. O. James Gear Mfg. Co.

Figure 9 — A transparent medium EP mineral cutting oil being used in hobbing small helical gears of AISI 4140 steel.

Additive Cutting Oils

For more severe operations it may be necessary to sulfurize the oils and/or include moderate quantities of E.P. additives. There are two general types of sulfurized oils used, i.e., those in which elemental sulfur is simply dissolved and those in which sulfur is reacted with the oil molecules and made to contain organic sulfur compounds as well as dissolved sulfur. The first type is normally light colored and the second dark. For severe service sulfurized oils which are highly compounded with additives may be required.

Cutting oil additives include the following, used either alone, or in various combinations: fatty oils and fatty acids, sulfurized fatty oils, chlorinated or sulfur-chlorinated oils, waxes, fats, etc. It is generally agreed that in addition to providing hydrodynamic lubrication, the use of additive materials enhances performance through formation of various types of films on the freshly cut metal surfaces which provide additional lubrication between the chip and tool.

Cutting Oils in Use Today

A recently completed survey of some 200 cutting fluids marketed by about 50 different suppliers revealed some pertinent information about the cutting oils in general use throughout the United States today. The cutting oils were collected at random from all parts of the country and are representative of fluids used in all types of machining operations. On the basis of data obtained in this survey, it may be summarized that today a typical or average cutting oil contains sulfur, chlorine and fat and has a Saybolt Universal Viscosity at 100°F. of 125 to 175 seconds. The fat content is below 5 per cent and the total sulfur and chlorine content lies between 1 and 3 per cent.

Current Trends

Many aspects of cutting oils have been improved in recent years. Two of the most significant trends in mineral cutting oils have been the development of transparent, heavy duty type products and the development of multipurpose oils for use as cutting oils, machine tool lubricants and hydraulic fluids.

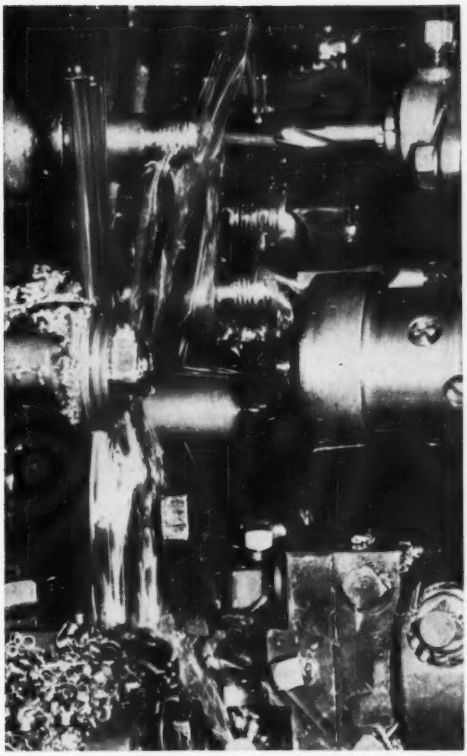
Transparent Cutting Oils

For many years the work horse of the metal cutting industry has been the dark colored highly sulfurized oils which possess excellent and desirable performance characteristics but in some machining operations are not acceptable because of their dark color and sometimes pungent odor. These limitations led to interest in transparent products. More detailed discussions of transparent cutting oils are available in an earlier issue of this publication.[5] Some of the advantages to be gained by using transparent oils are as follows:

1. Easier inspection of parts
   (a) increases production
   (b) reduces rejects
2. Cleaner shop, machines and parts
   (a) reduces clean up costs
3. Good psychological effect on personnel
   (a) greater production
   (b) more accurate work
   (c) less labor turnover

Although transparent products are not new, their widespread acceptance was long hampered by the fact that the early formulations generally possessed somewhat inferior performance characteristics. In recent years as a result of thorough research and development in both additive and cutting oil fields, new and improved transparent cutting oils have been formulated. The transparent products usually contain various quantities of selected sulfur and chlorine additives depending upon service requirements.

5. Magazine Lubrication, July 1951, "Transparent Cutting Oils".



Courtesy of Weatherhead Company of Canada, Ltd.

Figure 10 — Making ⅛ inch pipe plugs of B1113 steel. A multi-purpose oil is being used in this Davenport automatic and the threads are being rolled on.

Some products are designed for general machining such as the gear hobbing illustrated in Figure 9 and can be used as received, or cut back with mineral oils for light duty service. For heavy duty operations, higher percentages of the light colored additives are used and some are so effective that they rival the most highly compounded dark products in performance in the most severe operations. In order to provide superior finishes, varying percentages of fatty material are used depending upon the application.

Heavy duty low viscosity products (of approximately 60 SUS at 100°F.) are also available. These products have superior cooling characteristics in addition to desirable performance factors imparted by high compounding. The low viscosity products have been extremely satisfactory in machining the tough silicon-aluminum alloys. In addition, many special applications, such as deep hole gun-drilling, in both stainless steel and cast iron, can be done effectively. Tool life is greatly improved and in some instances the finishes are so excellent that it has been possible to eliminate honing steps previously found necessary.

Multi-Purpose Oils

In the metal working field, a multi-purpose oil is one that can be used as a cutting oil, a general machine lubricant and a hydraulic fluid for those machines which are hydraulically powered. Such oils are also referred to as dual and tri-purpose oils. Multi-purpose oils are admirably suited for use in automatic screw machines like those illustrated in Figures 10 and 11.

The use of multi-purpose oils in a shop presents many advantages, some of which are listed below.

1. Reduces oil inventories by consolidation of products required.

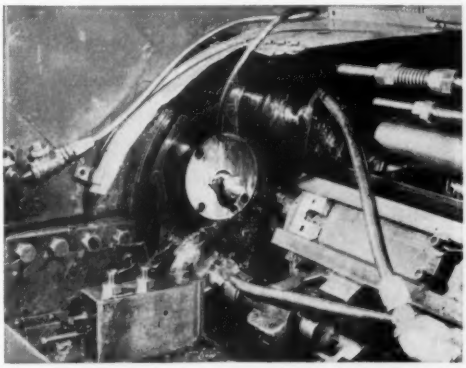
2. Eliminates the dangers of cross contamination of cutting oil, machine oil and hydraulic oil systems when filling or replenishing reservoirs.

3. Eliminates the objectionable features of cutting oil dilution by leakage from machine oil and hydraulic oil systems during operations.

4. Eliminates objectionable corrosion and deposit formation that might occur through leakage of cutting fluid into the machine oil and hydraulic oil systems. (Note: Purposeful use of oil from the cutting side of the machine in the other systems should be strictly avoided due to possibilities of contamination with metal chips, etc.)

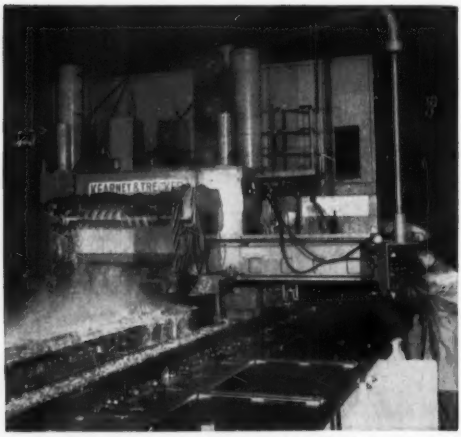
5. Provides good machining characteristics for both ferrous and non-ferrous metals.

Multi-purpose oils are usually prepared from selected paraffinic mineral oils to take advantage of their good oxidation characteristics and anti-fogging qualities. Both sulfur and chlorine additives are gen-



Courtesy of Bethandale Corporation

Figure 11 — A single multipurpose oil is being used as a cutting, lubricating and hydraulic oil in this 6 spindle automatic. This machine can be used to machine steel, brass or copper without changing cutting fluids which allows great versatility.



Courtesy of Lockheed Aircraft Corp.

Figure 12 — Soluble oil emulsion being used as coolant and lubricant as a combination spar and skin miller in airframe production.

erally used and they are chosen to be non-corrosive to copper yet possess desirable characteristics for machining both ferrous and non-ferrous metals. Oxidation and corrosion inhibitors may also be added. These oils are generally used in the medium viscosity range of 150 to 160 SUS at 100°F. Lower and higher viscosity products are also available for specific requirements.

Soluble Oils

The many and varied aspects of soluble oil composition, handling and care, emulsion preparation and usage have been thoroughly covered in previous issues of this publication[4, 6]. Discussions here will be limited to more general considerations.

One of the most important characteristics of soluble oils is product stability. This insures that all the desirable characteristics initially built into the formulation will be available when the product is put into use. Another most important factor is that they be properly and completely emulsified initially, otherwise only partial benefits will be obtained from their use.

Soluble oils in use today may be classed in the following four general categories:

1. General purpose
   a. Machining
   b. Grinding
2. Hard Water
3. Heavy Duty
4. Water Solutions
   "Chemicals" or "Synthetics"

4. Magazine Lubrication, April 1956, "Cutting Fluids".
6. Magazine Lubrication, July 1954, "Soluble Oils".

General Purpose Soluble Oils

General purpose soluble oils are used in various emulsion strengths depending upon the service. For general machining, emulsion strengths range from 3% to 20%. Figure 12 illustrates the use of such an oil in high-speed milling of airframe parts.

Due to the greater cooling efficiency obtained with emulsions, these mixtures provide superior performance to straight mineral oils in many instances and have replaced mineral cutting oils in various operations such as threading malleable iron pipe fittings shown in Figure 13.

For grinding, leaner emulsions are generally employed and concentrations generally vary from 1% to 2½%. This provides better cooling and improved chip settling. Richer emulsions tend to cause "loading" of abrasive wheels. In many large shops where central emulsion systems are used to supply fluid to a large number of machines for both machining and grinding, one emulsion is used which is made sufficiently rich to take care of the most severe machining operation and the most critical rusting condition.

There are usually some differences in compositions of the general purpose machining and grinding soluble oils. Soluble oils made specifically for grinding generally contain selected emulsifiers, for good rust protection and added detergency. Special additives may be used for increasing rust protection. In some instances lower viscosity mineral oils are used in products designed primarily for grinding.

Hard Water Soluble Oils

Hard water soluble oils are generally suitable for

Courtesy of Detroit Brass & Malleable Company

Figure 13 — A 10:1 soluble oil emulsion is being used as a cutting fluid in these automatic tappers making pipe elbows. The emulsion ratio used is governed by the severity of the operation. Rich emulsions are needed for more severe jobs yet there is plenty of cooling capacity available.

Courtesy of Jack & Heintz, Inc.

Figure 14 — Use of a soluble oil emulsion in precision low micro-finish cylindrical grinding. In this operation a soluble oil especially designed for use with hard water is being employed with no sacrifice in grinding and cooling efficiency.

either cutting or grinding, but may contain additional quantities of emulsifiers to combat the ravages of hard water components, or selected emulsifiers which resist reaction with the mineral salts in the water. There is no firm criterion to determine when hard water soluble oils are needed, however, generally they can be used profitably in water containing over 300 ppm hardness. Figure 14 illustrates such an application.

Heavy Duty Soluble Oils

Heavy Duty soluble oils generally contain high viscosity mineral oils (up to 750 Saybolt Universal Seconds at 100°F.) and sulfurized and chlorinated additives to impart E.P. characteristics. Recent advances have led to the development of outstanding products in this field. Heavy Duty soluble oil emulsions can be used in many severe operations formerly requiring highly compounded mineral cutting oils, for example the operation illustrated in Figure 15.

Water Solutions

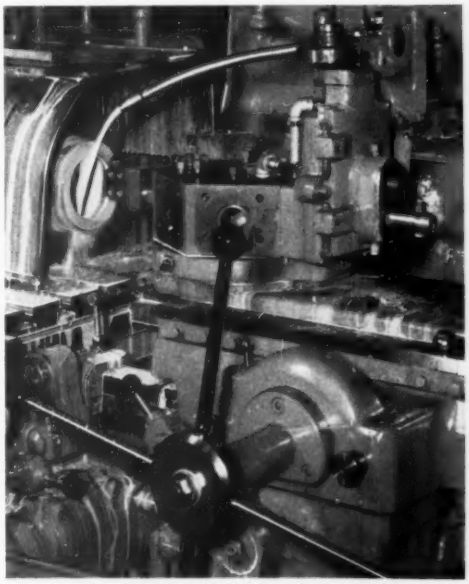
The use of transparent water solutions and translucent emulsions has grown considerably during the last few years.

The transparent water solutions are generally concentrated aqueous solutions of rust inhibiting inorganic salts (sodium nitrite, sodium borate, etc.), water soluble detergents, amines, polyglycols, etc. These fluids (cut back with water to varying degrees depending upon the strength of the initial concentrate) have found specific applications in tool room grinding, and in other grinding involving low stock removal with fine grit wheels. Their primary deficiencies are lack of lubricity, and high deposit forming tendencies.

The translucent emulsions are usually similar to conventional soluble oil formulations but the emulsifier content is generally very high (30 to 40%). These can be considered as special soluble oils with high detergency characteristics.

SELECTING THE CUTTING FLUID

Generally, there are factors other than the job requirement itself which govern the selection of the fluid to be used. Such things as price, operator preference, and the desire to consolidate stocks, among others, exert considerable influence. For every case where a set of operating conditions is fixed and a fluid is selected which will give the optimum results at those conditions, there will be another shop where the reverse is true, i.e., a fluid will be selected first, and the machining conditions then will be adjusted so that the optimum results will be obtained with that fluid. It is not uncommon to find a given part being machined successfully at different locations using different cutting fluids of widely varying characteristics. For example, in one shop a highly compounded oil of high E.P. level may be used on an operation where, at another



Courtesy of Eureka Williams Corp., Bloomington, Ill.

Figure 15 — Heavy duty soluble oil being used in a turret lathe for machining steel. Emulsion ratios may vary from 3:1 to 20:1 depending upon the severity of the operation.

shop, a soluble oil emulsion is employed. Obviously, the operating conditions of feed, speed and depth of cut were different at each shop.

In selecting a cutting fluid for a particular application, consideration must be given not only to the metal and nature of the operation but also to the type of tool, the operating conditions, and whether tool life, surface finish, or dimensional accuracy is the limiting factor. There are numerous general rules that can serve as guides in selecting the proper fluid for the job. Some of these are listed as follows:

1. Soluble oil emulsions and the chemical type water base fluids are basically coolants. They are most effective on operations where cuts are light and speeds are high. For maximum cooling, use as dilute an emulsion as possible without encountering rust. To improve the lubricating properties, increase the oil content of the emulsion.

2. Cutting oils containing E.P. agents are basically lubricants and are most effective on operations where cuts are heavy and speeds are low.

3. The effectiveness of E.P. additives decreases as cutting speeds increase due to a decrease in the contact time between the chip and the oil during which a chemical reaction and formation of a chemical film can take place.

4. Fatty material in an oil will improve surface finish.

5. If a built-up edge is forming on the tool, an oil containing more sulfur or chlorine will reduce this tendency.

6. Too high a concentration of E.P. additives can cause tool wear.

7. Increasing cutting speed will tend to decrease a built-up edge on the tool and improve surface finish.

8. For best results at very high speeds, carbide tools and the newer ceramic tools should be used, and usually emulsions or chemical water base fluids are recommended.

9. Cutting oils used for machining copper and copper alloys should contain no "active" sulfur, since staining of the workpiece would occur.

10. Soluble oil emulsions or water base fluids should never be used in machining magnesium because of a possible fire hazard.

11. Non-ferrous alloys such as the Inconels and Nimonics may be machined with "active" sulfur type oils. However, when these alloys are to be used in high temperature applications, as for example, in jet engines, the oil should be removed immediately after machining to avoid possible metal embrittlement.

12. In plain grinding, soluble oil emulsions may be used for all metals except magnesium. Sometimes a low viscosity straight mineral oil is preferable for copper and its alloys.

13. For form grinding of all metals except cast iron, a grinding oil containing sulfur, chlorine and fat is desirable. For cast iron, a low viscosity straight mineral oil is satisfactory.

14. In honing, low viscosity mineral oils alone or blended with various percentages of sulfurized oils and sulfurized fats are generally used.

15. For cold sawing, soluble oil emulsions or low viscosity straight mineral oils may be used for all metals.

16. Turning, planing, shaping, drilling, hobbing, boring, milling and reaming are accomplished satisfactorily on most metals with rich emulsions. Cutting oils of low to medium E.P. level may also be used.

17. Gear shaving, heavy duty broaching, threading and tapping on the various steels, Nimonics and Inconels require cutting oils containing sulfur, chlorine and fat of medium to high E.P. level. Soluble oils or cutting oils of low to medium E.P. level may be used on cast iron, copper and aluminum alloys.

It should be emphasized that the foregoing are merely guides that may be helpful in selecting a suitable cutting fluid for the various machining operations and cannot substitute for the services of an experienced metal working lubricant engineer.

SUMMARY

The metal working industry is a vital contributor to our industrial economy and strength. There are over 2,887,000 machine tools in the United States today.

Many new machines are being installed and older machines replaced with modern, more powerful ones, better designed for the desired higher speeds of production and for working the newer metals and alloys. Some larger shops are installing automated and semi-automated machine tool lines, particularly in the metal cutting field, to fulfill their greater requirements for production. Many of the changes in the metal working processes place a greater demand on the quality of the lubricants. The availability of high quality metal working lubricants has been one of the major contributing factors in overall advancement and progress in the metal working industries. These metal working lubricants were developed through intensive research by the lubricant suppliers.

Current demands on the metal working industries are higher than ever before and the ultimate success in meeting these demands is dependent to a large extent upon the availability of even higher quality metal working lubricants. The petroleum industry as a primary supplier of metal working lubricants will continue, through research and development, to make higher quality products available.

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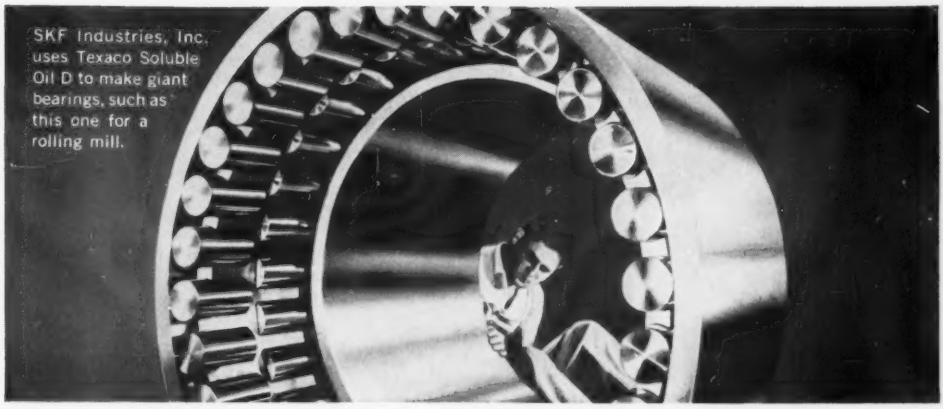
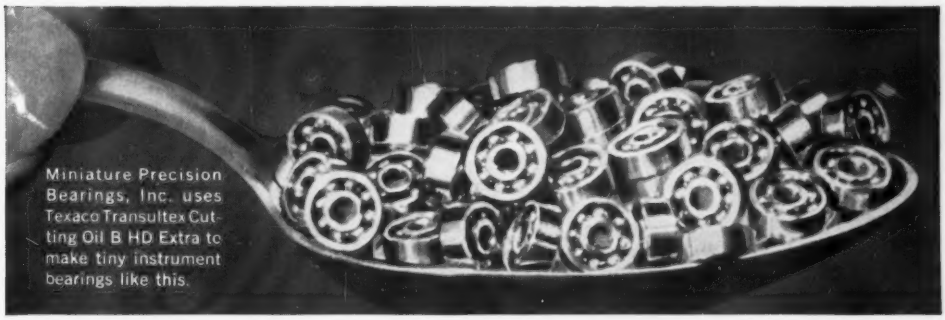


WHAT SIZE IS YOUR MACHINING PROBLEM?


Miniature Precision Bearings, Inc. uses Texaco Transultex Cutting Oil B HD Extra to make tiny instrument bearings like this.

If you make anti-friction bearings of any size, you need grinding fluids that prevent rust and produce uniformly fine finishes. These fluids must also take into account the bearing material and the operating condition of your machines. They must have specific stability, cooling properties and ability to settle grinding dirt quickly. Otherwise your production drops and the number of rejects rises.

The makers of the small and large bearings shown above get fine bearing finishes and high production by using Texaco. There is a complete line of Texaco Cutting, Grinding and Soluble Oils to help improve machining on every job.

Take this tip. Use Texaco Cutting, Grinding and Soluble Oils—they'll help you produce faster, better and at lower cost, whether your product is the largest or the smallest.

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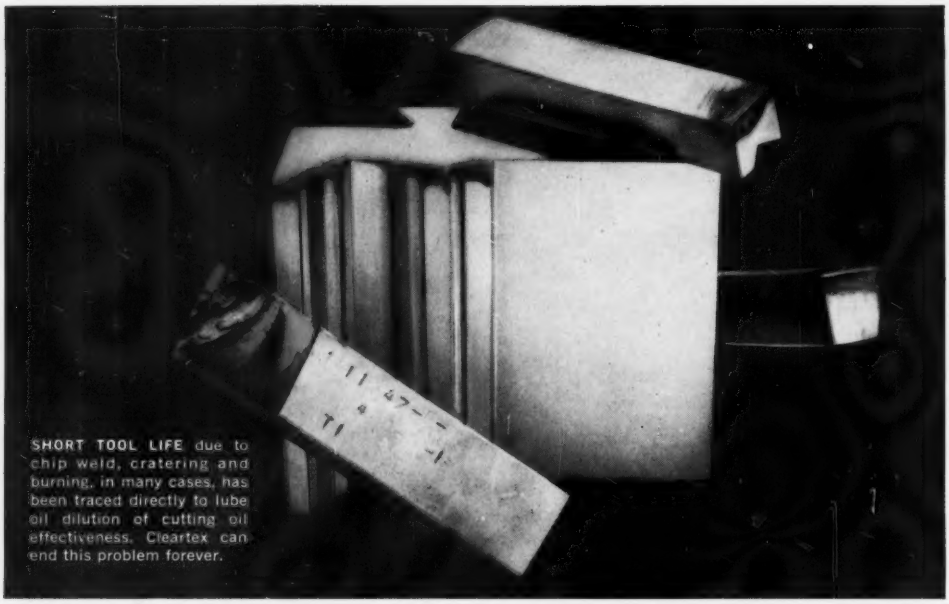

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DENVER 3, COLO.....1570 Grant Street

TEXACO

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MINNEAPOLIS 3, MINN.....1730 Clifton Place
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